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A determination of the K-conversion coefficient of the 6.1 sec $M4$ transition in Pb^{203}

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With 2 figures in the text

ABSTRACT

The K-conversion coefficient of the 825.2 keV $M4$ transition in Pb^{203} has been remeasured by comparing the K X-ray and gamma-ray intensities in the decay of the 6.1 sec isomeric state. The scintillation spectrum was measured with an improved technique in which two multichannel analyzers were utilized, one for the X-rays, the other for the isomeric gamma ray. The resulting value of $\varepsilon_K = 0.22 \pm 0.02$ is in good agreement with theory ($\beta_4 = 0.22$).

1. Introduction

The 6.1 sec $i_{13/2}$ state in Pb^{203} is populated in the 11.76 h electron-capture decay of Bi^{203}, and the $M4$ transition to the $f_{5/2}$ ground state has been studied in several investigations. The most accurate values of the energy and the half-life are 825.2 ± 0.5 keV [1] and 6.09 ± 0.10 sec [2]. The multipolarity assignment is based on the experimental values of half-life, internal conversion ratios and internal K-conversion coefficient [1]. So far, however, the last-mentioned quantity, which seems to be the most significant one for the multipolarity determination, has not been determined with very great precision because of experimental difficulties. The most accurate value, 0.24 ± 0.05, was recently determined by Stockendal [3], using a Bi^{203} source and applying the method of comparing internal and external conversion lines. A difficulty in this measurement is due to the interference between the close-lying conversion lines of the 820.1 and 825.2 keV transitions. Furthermore, in internal conversion, the K-conversion line of the former transition is very weak as compared with that of the latter transition, whereas in external conversion the opposite relation occurs.

The above difficulty would be eliminated by replacing the Bi^{203} source with a source of 6.1 sec Pb^{203m}. A possible method in this case for the conversion-coefficient determination would be the comparison between the K X-ray and gamma-ray photopeaks in the scintillation spectrum. Actually, such an experiment was once performed by Stockendal *et al.* [1]. The Pb^{203m} activity was "milked out" from an ion-exchange column in which the Bi^{203} source was absorbed, and the scintillation spectrum of the milked-out activity was obtained by using a two-channel method. One channel, the monitor, was centred on 825 keV and the position of the other

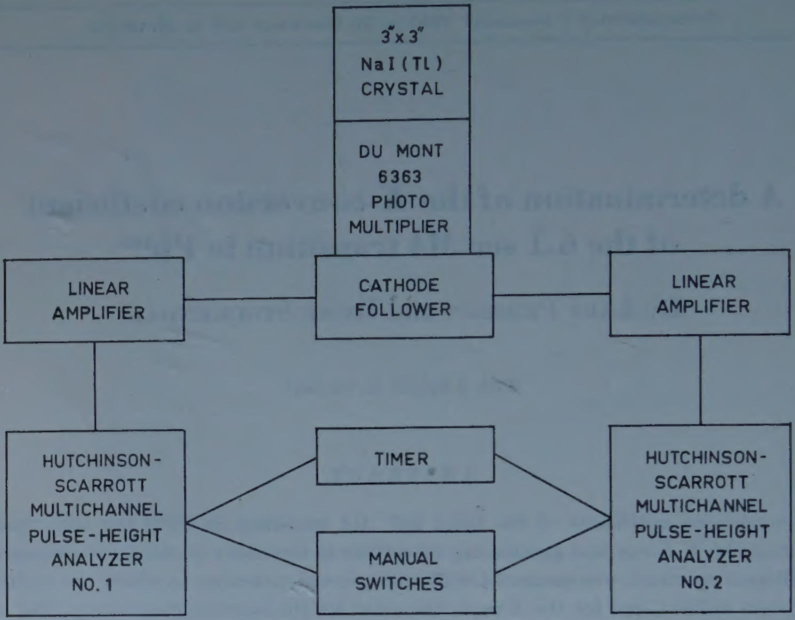

Fig. 1. Block diagram showing the electronic part of the experimental arrangement. The X-ray spectrum was studied in one of the analyzers, while the isomeric gamma ray was measured in the other.

channel was varied for every new milking. As a result of this measurement a lower limit of about 0.2 was obtained for the *K*-conversion coefficient. In the present investigation, however, the scintillation spectrum has been measured with an improved technique, which employed two 100-channel pulse-height analyzers. This resulted in a more precise determination of the *K*-conversion coefficient.

2. Scintillation apparatus

The scintillation spectrometer used included an ordinary Hilger 3″ × 3″ cylindrical NaI(Tl) crystal optically coupled to a 3″ Du Mont photomultiplier tube. By use of an iron shield, the background could be considerably decreased (cf. ref. [4]). A conical hole was made in the iron shield and the fixed position of the source was on the top of the cone, the envelope of which went through the bottom circumference of the crystal.

As shown in the block diagram of Fig. 1, pulses from the photomultiplier could be analyzed in two Hutchinson–Scarrott multichannel pulse-height analyzers. One analyzer was set up for the analysis of the X-rays in the decay of Pb^{203m} and the other analyzer for the measurement of the isomeric gamma ray. With this arrangement the number of points on each peak for every milking (see below) could be increased substantially as compared with the older arrangement [1]. In order to get suitable pulse-heights for the two analyzers, the linear amplifiers were at different settings. The analyzers could be switched on either simultaneously with the timer or, simultaneously or separately, with the manual switches.

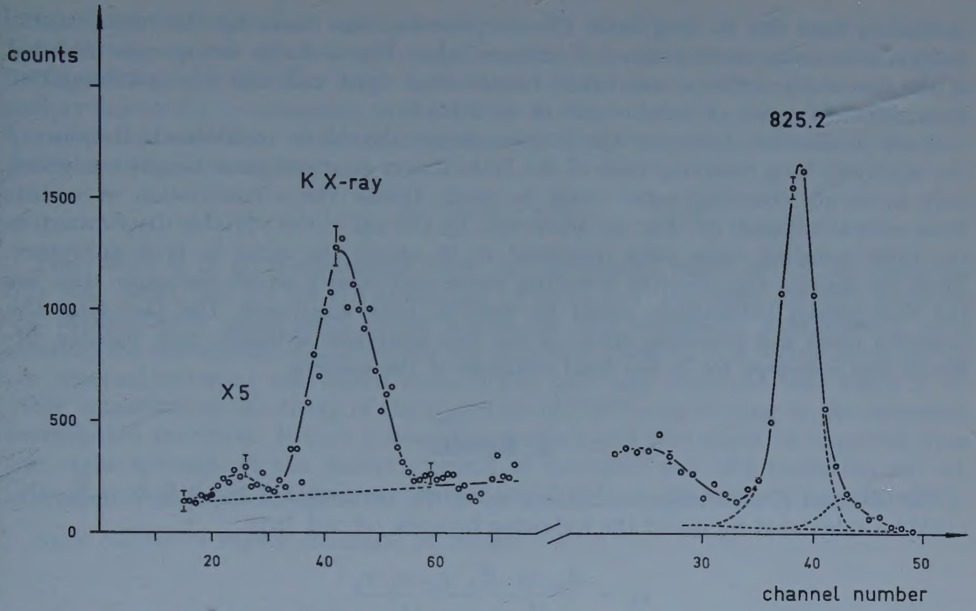

Fig. 2. Typical scintillation spectrum of 6.1 sec Pb^{203m} as obtained with two multichannel pulse-height analyzers. Counts from eight milkings were accumulated and the background was subtracted by the analyzers about 2 minutes after each measurement. The photopeak at about 900 keV is due to transitions in 68 min Pb^{204m}.

The efficiency calibration of the scintillation spectrometer was performed with the aid of radioactive sources of Hg^{203}, Au^{198}, Cs^{137}, Na^{22} and Na^{24}. In the first three cases use was made of the well-known procedure based on the relationship between the K-conversion coefficient of a transition and the K X-ray and gamma-ray photopeaks in the corresponding scintillation spectrum [5]. The following values of the K-conversion coefficients were used, being the mean values of the most accurate data available: 0.162 ± 0.003 (Hg^{203}, 279.1 keV) [6], 0.025 ± 0.001 (Au^{198}, 411.8 keV) [7–10] and 0.093 ± 0.005 (Cs^{137}, 661.6 keV) [11, 8]. The X-ray photopeaks were corrected to the iodine X-ray escape peak according to reported data [12] (correction checked in the case of Hg^{203}). In the case of the Na sources, the calibration was undertaken on the basis of the well-known relations of the radiation intensities [13].

3. Experimental procedures

The Bi^{203} source was obtained from a one-hour bombardment of radiogenic lead (mainly Pb^{206}) with about 50 MeV protons. After a chemical separation performed as described elsewhere [1], the bismuth activity was absorbed on an ion-exchange column. As outlined earlier [1], the grown-in Pb^{203m} activity could be rapidly washed out from the column into a thin glass tube and transferred to the source position of the scintillation spectrometer within three seconds of the commencement of the milking. The two multichannel analyzers were then immediately switched on with the timer for a measuring period of about 8 seconds. A subtraction of the background (including that due to long-lived Pb components) was made by the multichannel analyzers in a run started about 2 minutes later. Fig. 2 shows the spectra recorded in the two analyzers in a case where counts from eight milkings were accumulated. Four different series of measurements were made.

Some precautions taken in the measurements should be mentioned. Because of the relatively long resolving time of the Hutchinson–Scarrott pulse-height analyzers, only moderate counting rates could be used. Hence the accumulation of counts from several milkings (cf. Fig. 2). Moreover, by the aid of the variable discriminators the total counting rates were regulated to be about the same in both analyzers. Thus, by making the effective counting times very nearly equal, the same time for the background subtraction could be used in both analyzers. The fact that the counting rates and resolving times of the two analyzers actually were slightly different was corrected for in the final analyses of the spectra.

4. Results

The internal K-conversion coefficient ε_K of the investigated 825.2 keV transition could be calculated by use of the following formula (cf. ref. [5]):

$$\varepsilon_K = \frac{A_X \cdot e_\gamma \cdot E_X \cdot c_X \cdot c_1 \cdot c_2}{A_\gamma \cdot e_X \cdot \omega_K \cdot c_\gamma},$$

where

A_X, A_γ = recorded K X-ray and 825.2 keV gamma-ray intensities, respectively;
e_X, e_γ = crystal efficiencies for the K X-rays and 825.2 keV gamma rays, respectively;
E_X = iodine X-ray escape peak correction for the X-rays;
ω_K = fluorescence yield for the K-shell;
c_X, c_γ = corrections for the K X-ray and 825.2 keV gamma-ray absorptions, respectively, in the source-holder and in the mounting of the crystal;
c_1 = correction for the presence of Pb^{204m} X-rays;
c_2 = final correction for the different counting rates and resolving times of the analyzers.

The A_X and A_γ values were found from the areas under the photopeaks. As indicated by the peak at about 900 keV (see Fig. 2), the scintillation spectrum is slightly influenced by 68 min Pb^{204m}. The fraction of the X-ray intensity (about 2.2 %) originating from transitions in this isotope (mainly those of 374.7, 899.2 and 911.7 keV) was corrected for by the factor c_1. The calculation of c_1 was based on the known internal conversion data of Pb^{204m} [14].

The values of e_X and e_γ were obtained from the efficiency calibration curve experimentally found as described above (see Section 2). The values of E_X and ω_K were taken from references [12] and [15], respectively.

The absorption correction factors c_X and c_γ were calculated from a knowledge of the thicknesses and materials of the source-holder and of the mounting of the crystal. In the latter case the data given by the manufacturer were used. The last factor, c_2, is the final correction for the different counting rates and resolving times τ of the analyzers ($\tau_1 = 0.585$ msec, $\tau_2 = 0.680$ msec) (cf. Section 3).

Inserting the numerical values found for the quantities in the formula above, the following values of ε_K were found from the four series of measurements: 0.205, 0.232, 0.218 and 0.225. The error is estimated to be about 15 % in each case and is mainly due to the uncertainties in A_X (12 %), A_γ (7 %) and e_γ/e_X (8 %). The remaining quantities should all be accurate to within 1 %. Thus the mean value from the four determinations is found to be:

$$\varepsilon_K = 0.22 \pm 0.02.$$

This value is in good agreement with the theoretical value of 0.22 as found by Sliv and Band [16] for an $M4$ transition of 825.2 keV and thus strongly supports the multipolarity assignment found earlier for this transition. Furthermore, considering the consistency also with the experimental value of 0.24 ± 0.05 obtained by the internal–external conversion method [3], one may conclude that there is no other transition in the decay of the $i_{13/2}$ state of Pb^{203} contributing to the measured scintillation spectrum. If such a transition exists—and this might be expected from the slight anomaly of the matrix element of the 825.2 keV $M4$ transition (cf. ref. [3])—it must have an energy lower than about 25 keV, or else have very low intensity.

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